Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

Modifications to Improve the Standpipe Method of Determining the Permeability of Spawning Gravels for Stream Salmonids

J.C. Mason, T. Sweeten and W.E. McLean

Salmonid Enhancement Program
Department of Fisheries and Oceans
555 West Hastings Street, Suite 400
Vancouver, British Columbia
V6B 5G3

1992

Canadian Technical Report of
Fisheries and Aquatic Sciences
No. 1877

Fisheries and Oceans
Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 1877

1992

MODIFICATIONS TO IMPROVE THE STANDPIPE METHOD OF DETERMINING THE PERMEABILITY OF SPAWNING GRAVELS FOR STREAM SALMONIDS

by

J. C. Mason, T. Sweeten, and W. E. McLean

Salmonid Enhancement Program
Department of Fisheries and Oceans
555 West Hastings Street, Suite 400
Vancouver, British Columbia V6B 5G3

(c) Minister of Supply and Services Canada 1992

Cat. No. Fs 97-6/1877E ISSN 0706-6457

Correct citation for this publication:

Mason, J. C., T. Sweeten, and W. E. McLean. 1992. Modifications to improve the standpipe method of determining the permeability of spawning gravels for stream salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 1877: 11 p.

93-02685/

ABSTRACT

Mason, J. C., T. Sweeten, and W. E. McLean. 1992. Modifications to improve the standpipe method of determining the permeability of spawning gravels for stream salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 1877: 11 p.

Modifications to the Mark VI standpipe sampling system centering on a constant vacuum unit are described and the reliability of permeability measurements made using the modified system is assessed. Assessment considered operator skill and statistical properties of resulting permeability measurements made under standard conditions over a range of substrate size and permeability.

At permeabilities exceeding 60 $mL \cdot s^{-1}$ in uniform substrate exceeding 3.2 mm in diameter, the modified system allows detection of permeability change equal to or less than 30% of previous values from single observations. Skilled use of the sampling system provides further improvement in data quality at lower permeabilities with minor investment in training.

RÉSUMÉ

Mason, J. C., T. Sweeten, and W. E. McLean. 1992. Modifications to improve the standpipe method of determining the permeability of spawning gravels for stream salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 1877: 11 p.

On décrit les modifications apportées à un système d'échantillonnage à tube vertical Mark VI, dont la principale est une unité à vide constant, et la fiabilité des mesures de perméabilité qui on été effectuées à l'aide de ce système modifié sont évaluées. L'évaluation tenait compte de l'habileté de l'opérateur ainsi que des propriétés statistiques des mesures de permeabilité obtenues, effectuées dans les conditions normalisées pour un intervalle de taille et de perméabilité des substrats.

À des perméabilites supérieures à 60 mL/s dans un substrat uniforme de gravier de plus de 3,2 mm de diamètre, le système modifié permet la détection de changements de perméabilité égaux ou inférieurs de 30% aux valeurs antérieures provenant d'observations ponctuelles. L'utilisation experte de systèmes d'échantillonnage permet d'obtenir d'autres améliorations de la qualité des données a des perméabilités inferiéures, tout en ne nécessitant que peu de formation supplémentaire.

INTRODUCTION

Wickett (1954) and co-workers Pollard (1955) and Terhune (1958) developed the standpipe method for measuring gravel bed permeability in streams. Since the early 1960's, the method has been in general use to evaluate spawning bed quality for stream salmonids, including physico-chemical conditions and permeability reduction due to accelerated sedimentation in degraded river-beds, e.g. effects of logging, mining etc. Additional aims have included site-selection behaviour at the species level (Hansen, 1975).

Laboratory studies (e.g. Shumway et al, 1964) have considered the theoretical relationships between water velocity, temperature, and the oxygen requirements of embryonic salmonids. Fluvarium findings concerning respiratory physiology, hypoxial stress and competition (Mason, 1969) and those from numerous field studies have related watershed disruption and associated fine sediments with reduced embryo and alevin survival e.g. Wickett (1951), Cooper (1956). Various hydraulic flume studies have related sedimentation with particle size e.g. Cooper (1956) Beschta and Jackson (1979).

Despite this considerable background, some studies employing the standpipe method have failed to demonstrate that decreased gravel permeability reduces survival to emergence of stream salmonids (e.g. Coble, 1961; Hansen, 1975). The complex interaction of factors comprising the physico-chemical environment of the redd requires that measurement errors be minimized when documenting incubation conditions relative to stress and survival.

A more recent study by Young et al (1989), albeit performed in a small hydraulic flume, clearly documents that operator, site, and their interaction were major sources of variability in inflow readings performed under constant flow conditions, using the Mark VI system. Assuming that these variabilities were insuperable, these authors concluded that from 34 to 90 samples/site (mean of 55) were required to detect a 10% change in permeability-related inflow measurement in their flume, using five operators. The number of observations per site could be reduced to 9 to 23 (mean of 14) if detection level was reduced to 20%, and further reduced somewhat by using a single operator throughout time while sampling at similar water temperatures and flows. Lastly, Young et al (1989) concluded that, even under the latter conditions, readings should be interpreted as relative (index) values, rather than as accurate point estimates.

A review of measurement technology for determining intragravel flow in salmonid spawning beds led Chapman and McLeod (1987) to recommend the standpipe method. However, the findings of Young et al (1989) call into question the reliability of this method for surveys of streambed permeability in habitat and fish population studies.

In British Columbia, spawning channels are a major feature of the Salmon Enhancement Program (SEP) and production from these engineered facilities comprises the major portion of increased production attributed to a range of enhancement technology employed in the SEP.

Production from these channels varies by site and species of Pacific salmon but production efficiency and egg-to-fry survival are largely determined by water quality vis-a-vis sedimentation and depositional density (eggs m^{-2}). When the latter is controlled within optimum bounds, fry production is determined primarily by gravel bed quality at spawning and by sedimentation rates thereafter until emergence of fry.

Channel cleaning occurs in early summer, using various techniques for disturbing the gravel bed and flushing out the resulting re-suspended sediments. Monitoring of permeability prior to cleaning provides an indicator of "dirtiness" and the suspended sediment load is monitored during cleaning to allow calculation of the sediments removed. Following cleaning, the permeability is re-assessed to document the degree of permeability recovery.

We are developing monitoring instrumentation to assess the changes in sedimentation rate that accompany freshets during incubation, the aim being to reduce channel flow and incremental sediment addition during freshet. We monitor suspended sediments using continuous water sampling techniques. From these activities, it follows that both permeability as a summatory environmental factor determining fry production and the efficiency of channel cleaning operations must be assessed reliably.

We have been measuring permeability in spawning channels since 1985 using a modified Mark VI standpipe sampling unit. The original unit is characterized by variability between operators and site variability within operators. These difficulties are clearly shown in Young et al (1989). Manual operation of the modified bicycle pump producing a variable vacuum pressure is a major source of variability in measurement. Consequently, we switched to a powered system in 1987, replaced the manual pump with a constant vacuum unit, and developed a procedure to both estimate operator bias and standardize standpipe units for use at spawning channels.

This report describes the modifified Mark VI unit and presents data illustrating magnitude of operator bias and precision level attainable under standard conditions for a range of substrate size. Here, inflow rate is used interchangeably with permeability as a reliable parameter describing substrate conditions for salmonid eggs and larvae.

MODIFICATIONS AND METHODS

The constant vacuum sub-unit is composed of the following parts, and the prices are listed in Canadian dollars.

1.	Honda gasoline engine (GX110LX)	$440
2.	"Gast" vacuum pump (Mod.No. 1065-V2A)	479
	Specs.: 235 L^3 at 0 cm Hg, continuous maximum vacuum of 71 cm Hg, 0.5 HP	
3.	Metal jars for vac. pump (2)	18
4.	Pressure relief valve	22
5.	Vacuum guage, 0-76 cm	32
6.	Vacuum reservoir: 44.6 L. air tank	70
7.	45 m vacuum hose, rubber	400

The remaining parts, to complete the sampling unit include:

8.	Nalgene grad. cylinder, 1L marked in black	37
9.	Copper wand and miscell. fittings and valves	200
10.	Standpipe, fitted with a stainless steel head	130
	Total	1828

The procedures for obtaining permeability and other associated readings in spawning channels are outlined in Sweeten and Bennett (1991). Operator bias and standardized performance testing were conducted by measuring permeability in four graded series of particle sizes and in standing water alone. The particle size series ranged as follows: 1.6 to 3.2 mm; 3.2 to 6.4 mm; 6.4 to 12.7 mm; and 12.7 to 25.4 mm. The series were singly contained in 90 L plastic containers filled to a common water level, giving a substrate depth of 40 cm. The standpipe was inserted centrally in the substrates to a depth of 30 cm.

Each observation consisted of inserting the wand in the standpipe to a water depth of 2.5 mm, allowing a standard driving head, opening the vacuum valve to allow water into the graduate cylinder to a volume ranging between 600 and 800 mL, then closing

the valve while simultaneously lifting the wand from the water. An observer noted the elapsed time in seconds by stopwatch and calculated the rate of suctioned volume in $mL \cdot sec^{-1}$. The captured volume was then returned to the reservoir by draining the graduate cylinder and wand circuit. Free-water tests (no substrate) were performed to determine maximum potential reading and to compare probes.

Seven operators took nine successive observations at each of the four standard conditions. Three of the operators (1,6 and 7) were classified as highly skilled. One operator (2) had used the original Mark VI unit more than a decade previously and, with the three novice operators (3, 4 and 5), was given instruction and ten practice runs prior to the tests.

The resulting data were analyzed using Model II, one-way ANOVA, Tukey tests (pair-wise comparisons), and power tests (Zar, 1984). Precision of measurement and required sample sizes for detection of change were determined after Sokal and Rohlf (1981) and were related to operator experience.

RESULTS

Permeability as measured in the present tests was underestimated due to a systematic error in technique. Hydraulic head in the container was not held constant during withdrawal and the driving head declined by 0.6 cm during each test. Consequently, permeability values in standing water tests failed to exceed some values recorded in cleaned channels. This standardization error does not affect the results presented here other than by slightly underestimating permeability under the test conditions.

As expected, mean permeability rates increased with increased coarseness of substrate in the test series and ranged from 25.3 to 183.5 $mL \cdot s^{-1}$ (Table 1 and Fig 1). Operators 6 and 7 (highly skilled) also performed free-water tests with results as follows: 204.7 (SD = 5.9) and 208.0 (SD = 8.3) $mL \cdot s^{-1}$, respectively. Coefficients of variation (CV) ranged from 0.9 to 6.7% for all seven operators using the three coarsest substrate grades and averaged 3.2%. CV values for the finest grade (1.6 -3.2 mm) ranged from 3.2 to 19.2% averaging 13.5%, thus reflecting a marked increase in variability of measurement.

Despite the relatively minor differences among operators, these differences were significant at the 1% level for all four substrate sizes. Confining the ANOVA analysis to the more experienced operators (1, 2, 6 and 7) statistical differences remained in a mix of 5 and 1% levels except for the finest substrate (1.6-3.2 mm) where differences were rendered insignificant by the increased variability of measurement.

Power of the tests (O) by substrate grade ($\alpha = 0.05$) exceeded 0.99 for all substrate grade tests except for the very fine grade (1.6-3.2 mm) which had a 0.82 power rating.

Tukey tests were used to make operator pair-wise comparisons throughout the substrate grades (Table 2). Significant effects were confined almost entirely to the fine to coarse grades and appeared to be of random origin. Significant effects in the fine grade were concentrated in relatively high measurements made by operators 1 and 2. In the medium grade, significant effects were almost all associated with low measurements made by operator 5. In the coarse grade, significant effects were associated with relatively high measurements made by operator 4.

Sampling effort required at three levels of detection was determined for all seven operators and for the four most experienced operators (Table 3). More effort was required as permeability and particle size decreased and was influenced by operator experience. Effort for the experienced subgroup was less than one-half to almost one-fourth of that required by the over-all group at the 10 and 20% levels of detection. The experienced subgroup required only 1-2 observations to detect a 20% change in permeability in the three coarser substrates, and only one observation was required for both groups at the 30% level of detection. The finest substrate (sand) where permeabilities lower than 40 $mL \cdot s^{-1}$ were encountered, required considerable increase in sampling effort, and effort level by the inexperienced operators was greatly increased. Levels of precision for the experienced subgroup were about four times greater at the lower mean permeability readings (<35 $mL \cdot s^{-1}$) and twice as great at readings >100 $mL \cdot s^{-1}$) than those levels involving the entire group.

DISCUSSION AND CONCLUSIONS

Despite the role of experience, overall operator performance relative to precision of measurement was vastly improved over that reported by Young et al (1989) who used natural river gravels in a small laboratory flume. The present results disallowed any direct, quantitative comparison, reflecting incomparable test conditions, but do suggest that the modification described here offers significant improvement in operational reliability. With relatively minor instructional effort, only one observation is required to detect a significant 20% change in local permeability as measured at permanent standpipe sites.

With seasonally reduced permeability due to cumulative sediment load as winter progresses, as in engineered spawning channels operated at controlled and stable flows, one-tail statistical tests allow further improvement in detection level.

The influence of operator experience on sampling precision becomes very important at low permeabilities (<70 $mL \cdot s^{-1}$), as is shown in Table 3). We have found that low mean permeability readings (<35 $mL \cdot s^{-1}$) are not found in spawning channels producing an egg-to-fry survival rate exceeding 15% and are commonly associated with site-specific oxygen tensions below 2 $mg \cdot L^{-1}$ and fines of both organic and inorganic origins. Thus, reduced permeability due to increased sedimentation combines with the organic component (fines and biota) to reduce oxgen supply (Cooper, 1965), ultimately exposing salmonid embryos to lethal stress.

In their flume study using substrate claimed to typify the Laramie River, Young et al (1989) obtained relatively low and variable permeability readings. Their highest mean reading was 43 $mL \cdot s^{-1}$ and highest single reading was 57 $mL \cdot s^{-1}$. Four of five sites in the flume gave mean readings not exceeding 36 $mL \cdot s^{-1}$. As indicated in our data (Tables 1 and 3; Fig. 1) sampling variability and required sampling effort decreased rapidly when mean permeability exceeded 35 $mL \cdot s^{-1}$.

Strictly speaking, comparison of our data base with that from Young et al (1989) should be restricted to a comparable range of permeability readings. Hence, their data from sites 3, 4 and 5 can be compared with data from our "very fine" substrate (1.6-3.2 mm dia.) in terms of required sampling effort.

Effort levels given in their Table 3 appear to be grossly under-estimated if the data in their Table 1 are correct. Using our corrections to their Table 3, and comparing the re-calculated mean effort for their sites 3-5, we have not decreased required sampling effort at permeability readings below 40-50 $mL \cdot s^{-1}$ by employing the constant vacuum modification and operators of mixed skill level. However, only one-third of that effort was required by our four skilled operators, using the constant vacuum modification at these low permeabilities.

It would be instructive to compare sustained performance at the higher permeabilities as found in natural spawning beds of exceptional quality and in spawning channels (to 200 $mL \cdot s^{-1}$). We have noted inconsistent and flagging effort leading to significant variability in readings during intensive sampling effort schedules for channels when using the unmodified Mark VI sampling system.

In conclusion, we have alleviated a major technical weakness of the Mark VI standpipe sampling system by replacing the hand-driven vacuum unit with one providing a constant vacuum supply. This modification has greatly improved precision of inflow measurement at the higher permeability conditions uniformly found in clean spawning channels, relative to gravel beds in natural streams.

Single observations now allow detection of significant inflow change equal to or less than 20% of previous values exceeding 70 $mL \cdot s^{-1}$. For spawning channel operations, and target survivals of 70-80%, we can associate this inflow rate with an egg-to-fry survival rate of 50% or better for chum salmon in coastal systems.

The considerable improvement in performance shown by skilled operators suggests that much higher data quality can be obtained from modest investment in instruction and practice time.

The additional vacuum pump and reservoir units do not restrict use of our modified system to spawning habitats reachable only by vehicle. The modified system fits easily into a small inflatable boat or skiff for easy use in all but minor tributaries.

REFERENCES

Beschta, R. L. and W. L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. J. Fish. Res. Bd. Can. 36: 204-210.

Chapman, D. W. and K. P. McLeod. 1987. Development of criteria for fine sediment in the northern Rockies ecoregion. U.S. Environ. Prot. Agency, Region 10, Seattle, WA. EPA 910/9-87-162, 279 p.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90: 469-479.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. Int. Pac. Salmon Fish. Comm. Bull. 18: 71 p.

Hansen, E. A. 1975. Some effects of groundwater on brown trout redds. Trans. Amer. Fish. Soc. 104: 100-110.

Mason, J. C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. J. Fish. Res. Bd. Can. 26: 63-91.

Pollard, R. A. 1955. Measuring seepage through salmon spawning gravel. J. Fish. Res. Bd. Can. 12: 706-741.

Shumway, D. L., C. E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93: 342-356.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company, San Francisco, CA. 859 p.

Sweeten, T. and J. Bennett, 1991. Gravel sampling methods used in the assessment of spawning channels in the South Coast region. Canadian Dept. Fisheries and Oceans. Unpublished Manuscript, 16 p.

Terhune, L. D. B. 1958. The MARK VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Bd. Can. 15: 1027-1063.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Bd. Can. 11: 933-953.

Young, M. K., W. A. Hubert, and T. A. Wesche. 1989. Evaluation of variation in permeability measurements when using the MARK VI standpipe. Can. J. Fish. Aquat. Sci. 4: 447-450.

Zar, J. H. 1984. Biostatistical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. 718 p.

Table 1. Mean permeability rates (mL s^{-1}) for seven operators using the improved Mark VI standpipe unit in four graded substrates, under standardized conditions. Mean rates are based on 9 observations/cell, standard deviations in brackets.

		Substrate Grade (dia. in mm)			
Operator		1.6 - 3.2	3.2 - 6.4	6.4 - 12.7	12.7 - 25.4
1		38.0 (4.7)	80.6 (2.5)	144.5 (3.4)	174.9 (4.2)
2		36.3 (7.0)	87.8 (4.2)	148.7 (5.5)	167.9 (6.0)
3		30.5 (5.3)	74.1 (5.0)	147.8 (5.0)	162.8 (7.3)
4		25.3 (0.8)	72.4 (0.7)	154.1 (5.6)	183.5 (4.8)
5		30.5 (3.3)	72.9 (2.8)	131.5 (2.9)	164.5 (3.1)
6		42.6 (7.4)	77.6 (2.3)	148.3 (2.0)	164.3 (2.8)
7		39.8 (5.6)	77.9 (3.4)	152.1 (7.3)	172.1 (6.1)
	Means	34.7(10.8)	77.6 (5.9)	146.7 (8.3)	170.0 (9.8)
1,2, 6,7	Means	39.2 (6.5)	81.0 (5.2)	148.4 (5.5)	169.8 (6.3)

Table 2. Pair-wise comparisons (Tukey tests) of mean permeabilities by operator, for four graded substrates. (NS indicates no signficant difference; * difference at 5% level; ** difference at 1% level.

Substrate grade (dia. in mm)	Operator	Operator 1	2	3	4	5	6
Very Fine 1.6 - 3.2	2	NS					
	3	NS	NS				
	4	NS	NS	NS			
	5	NS	NS	NS	NS		
	6	NS	NS	NS	**	NS	
	7	NS	NS	NS	*	NS	NS
Fine 3.2 - 6.4	2	**					
	3	**	**				
	4	**	**	NS			
	5	**	**	NS	NS		
	6	NS	**	NS	*	*	
	7	NS	**	NS	**	*	NS
Medium 6.4 - 12.7	2	NS					
	3	NS	NS				
	4	**	NS	NS			
	5	**	**	**	**		
	6	NS	NS	NS	NS	**	
	7	*	NS	NS	NS	**	NS
Coarse 12.7 - 25.4	2	NS					
	3	**	NS				
	4	NS	**	**			
	5	*	NS	NS	**		
	6	*	NS	NS	**	NS	
	7	NS	NS	NS	*	NS	NS

Table 3. Number of permeability readings required to detect significant changes of 10, 20 and 30% of the mean permeability using the seven operators (wide range of skill) or using operators 1, 2, 6 and 7 (narrow range of high skill) at = 0.05, 1- = 0.80 for all four graded substrates. VF = very fine; F = fine; M = medium; C = coarse substrate.

	All 7 operators				4 skilled operators			
Percent change	VF	F	M	C	VF	F	M	C
10	206	11	9	8	45	9	3	3
20	53	3	2	2	13	2	1	1
30	18	1	1	1	7	1	1	1